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PLANT AND PROCESS FOR LIQUEFYING NATURAL GAS

10 FIELD OF THE INVENTION

The invention relates to novel plant and process for producing liquefied natural gas. The plant of the invention is of the type that comprises one natural gas pre-cooling heat exchanger having an inlet for natural gas and an outlet for cooled natural gas, optionally a distributor having an inlet connected to the outlet for cooled natural gas and having one or more outlets, and one or more main heat exchangers each comprising a first hot side having one inlet connected to one outlet of the distributor and an outlet for liquefied natural gas, which plant further comprises a pre-cooling refrigerant circuit for removing heat from the natural gas in the natural gas pre-cooling heat exchanger, and one or more main refrigerant circuits for removing heat from natural gas flowing through the first hot side of the corresponding main heat exchanger.

BACKGROUND OF THE INVENTION

US-P-4274849 and EP-A-0281821 disclose a process for liquefying a gas rich in methane, wherein the process utilizes two separate refrigeration cycles. Each cycle utilizes a multicomponent refrigerant. The low level (lower temperature) refrigerant cools and liquefies the natural gas in two stages by indirect heat exchange. The high level (higher temperature) refrigerant does not heat exchange with the natural gas to be liquefied, but cools the low level refrigerant by indirect heat exchange in an auxiliary heat exchanger.

US-P-6389844 discloses a plant of the type as disclosed above, in which the plant is such that the pre-cooling refrigerant circuit further comprises at least two additional circuits for removing heat from the main refrigerants in each of the main refrigerant circuits.

Such a plant, while it allows for a 40 to 60% increase of liquefaction capacity, still suffers from drawbacks. The liquefaction plant is still limited by the capacity of the propane compressor used in the pre-cooling refrigerant circuit.

The limited capacity of the propane compressor is still a problem for other usual plants. Solving this problem of limited capacity by the use of a pair of propane compressors in parallel on the same suction and discharge outlets is not satisfactory, since imbalanced load sharing and flow instability can then occur.

The invention aims at providing a novel plant and associated process for producing liquefied natural gas that is not limited by the propane compressor capacity.

SUMMARY OF THE INVENTION

The invention is based on the use of separate pre-cooling circuits: one for the pre-cooling of the natural gas and one for the pre-cooling of the main refrigerant.

The invention thus provides a plant as well as a process for liquefying natural gas.

In a first variant, the plant for liquefying natural gas comprises:

- (i) one pre-cooling heat exchanger having an inlet for natural gas and an outlet for cooled natural gas;
- (ii) one main heat exchanger comprising a first hot side having one inlet connected to the outlet of the heat exchanger and an outlet for liquefied natural gas;

(iii) one main refrigerant circuit for removing heat from natural gas flowing through the first hot side of the main heat exchanger;

5 (iv) a pre-cooling refrigerant circuit for removing heat from the natural gas in the pre-cooling heat exchanger;

and further comprises

10 (v) one additional circuit for removing heat from the main refrigerant in the main refrigerant circuit, where this circuit is separate from the pre-cooling refrigerant circuit for natural gas;

and wherein said main refrigerant circuit is separate from the pre-cooling refrigerant circuit.

15 In one embodiment, in the plant of the first variant, the additional circuit comprises a heat exchanger, a compressor, a cooler, and an expansion device, the compressor having an inlet and an outlet, said outlet being connected by means of a conduit to said cooler, said
20 conduit extending via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said compressor.

In this first variant, the process for liquefying
25 natural gas comprises:

(i) pre-cooling natural gas in a pre-cooling heat exchanger into a flow of pre-cooled natural gas;

30 (ii) liquefying said pre-cooled gas flow in one heat exchanger comprising a first hot side having one inlet connected to the outlet of the heat exchanger for pre-cooled natural gas and an outlet for liquefied natural gas;

35 (iii) removing heat from the natural gas flowing through the first hot side of the main heat exchanger using a main refrigerant circuit;

(iv) removing heat from the natural gas in the pre-cooling heat exchanger for pre-cooled natural gas using a pre-cooling refrigerant circuit;

and further comprises

5 (v) removing heat from the main refrigerant in the main refrigerant circuit, in one additional circuit where the step of removing heat from the main refrigerants is separate from the step of removing heat from the natural gas in step
10 (iv);

and wherein the step of removing heat from the natural gas in step (iv) does not make use of said main refrigerant circuit.

Said process is especially carried out in the plant of
15 the first variant.

In a second variant, the plant for liquefying natural gas comprises:

20 (i) one pre-cooling heat exchanger having an inlet for natural gas and an outlet for cooled natural gas;

(ii) a distributor having an inlet connected to the outlet for cooled natural gas and having at least two outlets;

25 (iii) at least two main heat exchangers each comprising a first hot side having one inlet connected to one outlet of the distributor and an outlet for liquefied natural gas;

30 (iv) at least two main refrigerant circuits for removing heat from natural gas flowing through the first hot side of the corresponding main heat exchanger;

35 (v) a pre-cooling refrigerant circuit for removing heat from the natural gas in the pre-cooling heat exchanger;

and further comprises

(vi) at least two additional circuits for removing heat from the main refrigerants in each of the

main refrigerant circuits, where these circuits are separate from the pre-cooling refrigerant circuit for natural gas;

and wherein said main refrigerant circuits are
5 separate from the pre-cooling refrigerant circuit.

In one embodiment, in the plant of the second variant, the circuits each comprise a heat exchanger, a compressor, a cooler, and an expansion device, the compressor having an inlet and an outlet, said outlet being connected by means
10 of a conduit to said cooler, said conduit extending via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said compressor.

15 In another embodiment, in the plant of the second variant, the circuits comprise each a heat exchanger and an expansion device, and further comprise one compressor and one cooler, the compressor having an inlet and an outlet, said outlet being connected by means of conduit to said one
20 cooler, said conduit being divided into conduits connected via said expansion device, to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said one compressor.

25 In yet another embodiment, in the plant of the second variant, the circuits comprise an integrated heat exchanger and an expansion device, and further comprise one compressor and one cooler, the compressor having an inlet and an outlet, said outlet being connected by means of
30 conduit to said one cooler, said conduit being connected via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of return conduit to the inlet of said one compressor.

35 In a preferred embodiment, the plant of the second variant comprises two main heat exchangers, two main refrigerant circuits and two additional circuits.

In this second variant, the process for liquefying natural gas comprises:

5 (i) pre-cooling natural gas in a pre-cooling heat exchanger into a flow of pre-cooled natural gas;

(ii) distributing said flow of pre-cooled natural gas into at least two distributed pre-cooled gas flows;

10 (iii) liquefying said at least two distributed pre-cooled gas flows in at least two main heat exchangers each comprising a first hot side having one inlet receiving one distributed pre-cooled gas flow and an outlet for liquefied natural gas;

15 (iv) removing heat from the natural gas flowing through the first hot side of the corresponding main heat exchanger using two main refrigerant circuits;

20 (v) removing heat from the natural gas in the pre-cooling heat exchanger using a pre-cooling refrigerant circuit;

and further comprising

25 (vi) removing heat from the main refrigerants in each of the main refrigerant circuits, in at least two additional circuits where the step of removing heat from the main refrigerants is separate from the step of removing heat from the natural gas in step (v);

30 and wherein the step of removing heat from the natural gas in step (iv) does not make use of said main refrigerant circuits.

Said process is especially carried out in the plant of the second variant.

35 In a further embodiment, in the plant of the invention, the first pre-cooling refrigerant circuit comprise a heat exchanger, a compressor, a cooler, and an expansion device, the compressor having an inlet and an

outlet, said outlet being connected by means of a conduit to said cooler, said conduit extending via said expansion device to the inlet of the cold side of said heat exchanger, the outlet of the cold side of said heat exchanger being connected by means of a return conduit to the inlet of said compressor.

In yet a further embodiment, the plant of the invention further comprises:

downstream said first pre-cooling heat exchanger, a pretreatment for removing part of the heavy components from the gas.

In yet a further embodiment, the process of the invention further comprises:

pretreating flow of pre-cooled natural gas for removing part of the heavy components from the gas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows schematically the liquefaction plant according to the present invention;

FIG. 2 shows schematically another embodiment of the invention;

FIG. 3 shows schematically an alternative of the embodiment shown in FIG. 2;

FIG. 4 shows schematically a further alternative of the embodiment shown in FIG.2; and

FIG. 5 shows schematically a further alternative of the embodiment shown in FIG.2.

DETAILED DESCRIPTION OF THE INVENTION

Reference is made to FIG. 1. The plant for liquefying natural gas according to the present invention comprises one natural gas pre-cooling heat exchanger 2, a pre-cooling refrigerant circuit 3, one main heat exchanger 5, and one main refrigerant circuit 9.

The natural gas pre-cooling heat exchanger 2 has a hot side in the form of tube 12 that has an inlet 13 for natural gas and an outlet 14 for cooled natural gas. The

tube 12 is arranged in the cold side or shell side 15 of the natural gas pre-cooling heat exchanger 2.

The liquefaction heat exchanger 5 comprises a first hot side 25 having one inlet 26. The inlet 26 of the first hot side 25 is connected to the outlet 14 of the heat exchanger 2, by means of conduit 27. The hot side 25 has an outlet 28 at the top of the liquefaction heat exchanger 5 for liquefied natural gas. The first hot side 25 is located in the cold side 29 of the liquefaction heat exchanger 5, which cold side 29 has an outlet 30.

The pre-cooling refrigerant circuit 3 comprises a turbine-driven pre-cooling refrigerant compressor 31 having an inlet 33 and an outlet 34. The outlet 34 is connected by means of conduit 35 to a cooler 36, which may be an air cooler or a water cooler. Conduit 35 extends via an expansion device in the form of a throttle 38 to the inlet 39 of the cold side 15 of the natural gas pre-cooling heat exchanger 2. The outlet 40 of the cold side 15 is connected by means of return conduit 41 to the inlet 33 of the turbine-driven pre-cooling refrigerant compressor 31.

In contrast with US-P-6389844, the pre-cooling refrigerant circuit 3 does only pre-cool the natural gas, and does not serve to pre-cool the refrigerant in the main refrigerant circuit 9 (and 9' as identified in said US-P-6389844). Also, the pre-cooling refrigerant circuit is separate from the main refrigerant circuit (9), in contrast with US-P-4274849 and EP-A-0281821.

To perform the pre-cooling in this main refrigerant circuit, the plant of the invention comprises one additional circuit 43. The additional circuit 43 comprises a turbine-driven pre-cooling refrigerant compressor 131 having an inlet 133 and an outlet 134. The outlet 134 is connected by means of conduit 135 to a cooler 136, which may be an air cooler or a water cooler. Conduit 135 extends through conduit 144 via an expansion device in the form of a throttle 45 to the inlet 139 of the cold side 85 of the heat exchanger 58. The outlet 140 of the cold side is connected by means of return conduit 146 to the inlet 133

of the turbine-driven pre-cooling refrigerant compressor 131.

The liquefaction refrigerant circuit 9 comprises a gas turbine-driven liquefaction refrigerant compressor 50 having an inlet 51 and an outlet 52. The outlet 52 is connected by means of conduit 54 to a cooler 56, which may be an air cooler or a water cooler, and the hot side 57 of a refrigerant heat exchanger 58 and to a separator 60. The separator 60 has an outlet 61 for liquid at its lower end and an outlet 62 for gas at its upper end.

The liquefaction refrigerant circuit 9 further includes a first conduit 65 extending from the outlet 61 to the inlet of a second hot side 67 that extends to a mid point of the liquefaction heat exchanger 5, a conduit 69, an expansion device 70 and an injection nozzle 73.

The liquefaction refrigerant circuit 9 further includes a second conduit 75 extending from the outlet 62 to the inlet of a third hot side 77 that extends to the top of the liquefaction heat exchanger 5, a conduit 79, an expansion device 80 and an injection nozzle 83.

The refrigerant heat exchanger 58 includes a cold side 85 that is included in the additional circuit 43.

During normal operation, natural gas is supplied to the inlet 13 of the hot side 14 of the natural gas pre-cooling heat exchanger 2 through conduit 90. Pre-cooling refrigerant is removed from the outlet 40 of the cold side 15 of the natural gas pre-cooling heat exchanger 2, compressed in the turbine-driven pre-cooling refrigerant compressor 31 to an elevated pressure, condensed in the condenser 36 and allowed to expand in the expansion device 38 to a low pressure. In the cold side 15 the expanded pre-cooling refrigerant is allowed to evaporate at the low pressure and in this way heat is removed from the natural gas.

Pre-cooled natural gas removed from the hot side 14 is passed to the heat exchanger 5.

An optional pretreatment can also be contemplated in the invention, where the pretreatment unit 100 would be

located after heat exchanger 2. Such a pretreatment unit would aim at withdrawing most part of the heavy components, typically part or all of the C2, C3, C4, C5 and heavier components of the gas. The resulting flow exiting from the pretreatment would comprise mostly methane. This flow will then be directed to the main heat exchanger 5.

Through conduit 27 the pre-cooled natural gas is supplied to the inlets 26 of the first hot side 25 of the main heat exchanger 5. In the first hot side 25 the natural gas is liquefied and sub-cooled. Sub-cooled natural gas is removed through conduit 95. The sub-cooled natural gas is passed to a unit for further treating (not shown) and to tanks for storing the liquefied natural gas (not shown).

Main refrigerant is removed from the outlet 30 of the cold side 29 of the liquefaction heat exchanger 5, connected through conduit 53 to inlet 51 of the turbine-driven liquefaction compressor 50, where it is compressed to an elevated pressure. The heat of compression is removed in cooler 56 and further heat is removed from the main refrigerant in the refrigerant heat exchanger 58 to obtain partly condensed refrigerant. Partly condensed main refrigerant is then separated in separator 60 into a heavy, liquid fraction and a light, gaseous fraction, which fractions are further cooled in the second and the third hot side 67 and 77 respectively to obtain liquefied and sub-cooled fractions at elevated pressure. The sub-cooled refrigerants are then allowed to expand in expansion devices 70 and 80 to a lower pressure. At this pressure the refrigerant is allowed to evaporate in the cold side 29 of the liquefaction heat exchanger 5 to remove heat from the natural gas passing through the first cold side 25.

In the above described embodiment, the refrigerant used in the pre-cooling circuits is suitably each time a single component refrigerant, such as propane, or a mixture of hydrocarbon components or another suitable refrigerant used in a compression cooling cycle or in an absorption cooling cycle. Preferably this pre-cooling refrigerant is propane. The main refrigerant is suitably a multi-component

refrigerant comprising nitrogen, methane, ethane, propane and butane.

The natural gas pre-cooling heat exchanger 2 comprises suitably a set of two or more heat exchangers arranged in series, wherein pre-cooling refrigerant is allowed to evaporate at one or more pressure levels. Suitably, the refrigerant heat exchanger 58 comprises a set of two or more heat exchangers arranged in series, wherein the pre-cooling refrigerant is allowed to evaporate at one or more pressure levels.

The main heat exchanger 5 can be of any suitable design, such as a spool wound heat exchanger or a plate-fin heat exchanger.

In the embodiment as described with reference to FIG. 1, the liquefaction heat exchanger 5 has a second and a third hot side, 67 and 77, respectively. In an alternative embodiment, the liquefaction heat exchanger has only one hot side in which the second and the third hot side are combined. In this case the partly condensed main refrigerant is directly supplied to the third hot side 77, 77', without separating it into a heavy, liquid fraction and a light, gaseous fraction. The liquefaction heat exchanger 5 can also be of any suitable design, as may be readily understood by the skilled man.

The compressors 31, 50 and 131 can be multi-stage compressors with inter-cooling, or a combination of compressors in series with inter-cooling in between two compressors, or a combination of compressors in parallel (albeit this latter solution is not preferred).

Instead of turbines, electric motors can be used to drive the compressors 31, 50 and 131 in the pre-cooling refrigerant circuit 3 and the main refrigerant circuit 9, and the pre-cooling refrigerant circuit 43.

The turbine (not shown) in the pre-cooling refrigerant circuit may be a steam turbine. In this case suitably, the steam required to drive the steam turbine is generated with heat released from cooling the exhaust of the gas turbines (not shown) of the main refrigerant circuits.

Reference is now made to FIG. 2, which shows schematically another embodiment of the invention. As one will immediately notice, the heat exchanger has been now
 5 duplicated (as in US-P-6389844). The plant for liquefying natural gas comprises one natural gas pre-cooling heat exchanger 2, a pre-cooling refrigerant circuit 3, a distributor 4, and two main heat exchangers 5 and 5', and two main refrigerant circuits 9 and 9'. For this FIG. 2,
 10 the second heat exchanger 5', and main refrigerant circuit 9' comprise the same elements than the first heat exchanger and main refrigerant circuit, save that these parts are referenced with prime numbers. The pretreatment has not been shown in FIG. 2, as it is optional.

15 The distributor 4 has an inlet 18 connected by means of conduit 19 to the outlet 14 for cooled natural gas and two outlets 22 and 23. Each liquefaction heat exchanger 5, 5' comprises a first hot side 25, 25' having one inlet 26, 26'. The inlet 26 of the first hot side 25 is connected to
 20 the outlet 22 of the distributor 4 and the inlet 26' of the first hot side 25' is connected to the outlet 23, by means of conduits 27 and 27', respectively.

In one embodiment, the main refrigerant circuits 9 and 9' are identical to each other and so are the main heat
 25 exchangers 5 and 5'.

During normal operation, natural gas is supplied to the inlet 13 of the hot side 14 of the natural gas pre-cooling heat exchanger 2 through conduit 90. Pre-cooled natural gas removed from the hot side 14 is passed to the
 30 distributor 4 through conduit 19. Through conduits 27 and 27' the pre-cooled natural gas is supplied to the inlets 26 and 26' of the first hot sides 25 and 25' of the main heat exchangers 5 and 5'. The other operations are identical to the ones disclosed in relation with FIG. 1 (with one heat
 35 exchanger 5 and one main refrigerant circuit 9). Hence, in the first hot side 25, 25' the natural gas is liquefied and sub-cooled. Sub-cooled natural gas is removed through conduits 95 and 95'. In one embodiment, the amounts of

natural gas passing through conduits 27 and 27' are equal to each other.

The liquefaction refrigerant circuits 9 and 9' comprise refrigerants that may have the same composition. 5 These circuits 9 and 9' can, if desired, either be connected by a conduit (not shown) or even form one refrigerant circuit only.

In the embodiment of FIG. 2, each main refrigerant circuit 9 and 9' comprises a complete pre-cooling circuit 10 43 and 43', where each pre-cooling circuit is identical to the one disclosed in FIG. 1.

Reference is now made to FIG. 3, which shows schematically another embodiment of the invention. As in 15 FIG. 2, the plant comprises two main heat exchangers 5 and 5', and two main refrigerant circuits 9 and 9'. In FIG. 3, the two additional circuits 43 and 43' share the same compressor 131 and cooler 136. A manifold 142 is connected at the outlet of the cooler to distribute the refrigerant 20 to the expansion device (throttle 45 and 45') through conduits 143 and 143'. The return conduits 146 and 146' are connected to the inlet 133 of the compressor 131, either directly or through a manifold (not shown).

25 In one embodiment, the compressors 31 and 131 (or optionally 131 and 131') can be driven by the same turbine.

Reference is now made to FIG. 4, which shows schematically an alternative of the pre-cooling refrigerant 30 circuits 43 and 43' as shown in FIG. 3. The refrigerant heat exchangers 58 and 58' shown in FIG. 3 are combined in one integrated heat exchanger 202. The integrated heat exchanger 202 has a cold side 215 in which are arranged the hot sides 57 and 57' pertaining to the main refrigerant 35 circuits 9 and 9', respectively. In this embodiment, the pre-cooling refrigerant is suitably a multi-component refrigerant comprising nitrogen, methane, ethane, propane and butane. During normal operation, evaporated pre-cooling

refrigerant is removed from the cold side 215 through conduit 241, compressed to an elevated pressure by the pre-cooling refrigerant compressor 231 (having an inlet 233 and an outlet 234), cooled in cooler 236 through conduit 235 and supplied to additional hot side 243 arranged in the cold side of the integrated heat exchanger 202. In the additional hot side 243, the pre-cooling refrigerant is liquefied against evaporating refrigerant. The liquefied pre-cooling refrigerant is removed from the additional hot side 243 through conduit 245 provided with expansion device in the form of throttle 246, where it is allowed to expand to a lower pressure. At this lower pressure the refrigerant is supplied through injection nozzle 248 into the inlet of the cold side 215.

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Reference is made to FIG. 5 showing an alternative of the embodiment of FIG. 4, wherein the pre-cooling refrigerant compressor 231 is a two-stage compressor (having two inlets 233 and 233' and an outlet 234). The two-stage compressor 231 supplies refrigerant at elevated pressure to the additional hot side 243' of the first stage integrated pre-cooling heat exchanger 202', wherein part of the refrigerant is allowed to evaporate at intermediate pressure in the cold side 215'. The remainder is passed through conduit 250 to the additional hot side 243 of the second stage integrated pre-cooling heat exchanger 202, this refrigerant is allowed to evaporate at low pressure in the cold side 215. The inlets 233 and 233' of the two-stage compressor 231 are connected to the cold sides 215 and 215' of the heat exchangers 202 and 202' by conduits 241 and 241', respectively. In the first and second stage heat exchangers 202 and 202' the liquefaction refrigerant of each of the liquefaction refrigerant circuits is pre-cooled in hot sides 57 and 57'. For the sake of clarity the conduits interconnecting the latter hot sides have not been shown.

It would also be possible to have one compressor only, with two coolers for each circuit, a manifold being this time arranged at the outlet of the compressor to distribute the refrigerant to each cooler.

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The pre-cooling refrigerant circuits in the invention are separate. The ratio of compression power between the pre-cooling circuit 3 and the additional circuit 43 (43 and 43' if and when present) is for example from 15:85 to 40:60, typically about 25:75.

An advantage of the present invention is that the conditions of pre-cooling and liquefaction, for example the compositions of the refrigerant, can easily be adapted such that an efficient operation is achieved. Moreover, in case one of the liquefaction circuits has to be taken out of operation, the conditions can be adapted to work efficiently with a single liquefaction train.